Charge Spectrometry for Xe^{133}-Cs^{133}

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The distribution in charge of the product atoms of the radioactive decay Xe^{133}-Cs^{133} has been examined under magnetic analysis. The relative intensities are found to be as follows, expressed in percent of the decay events, and going respectively from charge 1 through charge 23: 34.1, 3.74, 2.27, 2.15, 2.99, 4.27, 6.14, 9.5, 12.3, 9.0, 6.06, 3.32, 1.76, 1.06, 0.66, 0.32, 0.13, 0.050, 0.014, 0.0075, 0.0027, 0.0013, 0.0005. In interpreting this charge spectrum, the initial part (charges 1 through 4) is attributed mainly to atoms that escape internal conversion, and the subsequent rise to a maximum at charge 9 and decrease to charge 23 is attributed to atoms that suffer internal conversion. The ratio of the intensities of the two parts of the distribution gives a total internal conversion coefficient for the K, L, and M shells of 1.4, in rough agreement with work of others. Comparison is made with the charge spectrum arising from internal conversion in Xe^{131m}-Xe^{131}, which had previously been measured in the same apparatus. From the low-charge end of the spectrum, the probabilities of electron loss as a result of the beta decay alone are derived as follows: no-electron loss, 0.8; 1-electron loss, 0.08; 2-electron loss, 0.04; 3-electron loss, 0.03. The high-charge side of the spectrum shows a shallow dip in the region of charges 12, 13 and 14, and beyond that point there is relatively more intensity in Xe^{133}-Cs^{133} than there is in Xe^{131m}-Xe^{131}. The difference in shape probably results both from the higher $K/(L+M)$ conversion ratio of Xe^{133}-Cs^{133} as compared with Xe^{131m}-Xe^{131}, and from the fact that the beta emission in Xe^{133}-Cs^{133} introduces electron loss by shake-off. The dip at charges 12, 13, and 14 suggests an underlying structure in the total distribution, comprising subspectra associated with the individual electron shells in which the vacancy cascades originate.

OBSERVATIONS of the charge spectra produced in atoms following radioactive decay have been limited, so far, to simple, unmixed modes of disintegration: the work[1] on Kr^{85}-Rb^{85}, for example, showed the kind of spectrum that follows a case of pure beta decay, the surveys[2,3] of A^{37}-Cl^{37} were concerned with a case of pure electron capture, and the investigation[4] of Xe^{131m}-Xe^{131} dealt with pure internal conversion.

In a case such as that of Kr^{85}-Rb^{85}, the ionizing process is an electric excitation which results from the change in the nuclear charge and has the primary effect of "shaking-off" an electron, usually one from the outside of the atom. The resulting spectrum drops sharply from charge 1 toward higher charges. The spectra for A^{37}-Cl^{37} and Xe^{131m}-Xe^{131}, on the other hand, start at low intensity for charge 1, rise to a maximum, and then decrease again at high-charge values. This kind of spectrum is yielded by events that produce as a primary result a hole in one of the inner electron shells, with the consequence that a cascade of vacancies is usually initiated which propagates through the action of successive radiationless transitions. It is natural now to ask what happens when these processes occur *in combination*, for example, in a radioactive transformation for which charged particle emission is followed by internal conversion. It is in this connection that Xe^{133}-Cs^{133} becomes of interest.

The 5.3-day activity in Xe^{133} consists of beta emission followed in about 35% of the events by gamma emission, and in the remaining 65% by internal conversion. Gamma emission can be expected to have only a weak coupling with the atomic electron structure, and its ionizing effects will probably be negligible so far as present considerations are concerned. If such is the case, the atoms that escape internal conversion should exhibit a charge spectrum characteristic of pure beta emission, qualitatively like that of Kr^{85}-Rb^{85}. On the other hand, the atoms that undergo internal conversion can be subdivided into two groups; *viz.*, those which escape electric excitation arising from the alteration in nuclear charge, and those in which electric excitation or ionization may be compounded with the vacancy cascade process. The former subgroup should show a charge spectrum characteristic of pure internal conversion, and therefore, somewhat similar to the spectrum that we have already studied in Xe^{131m}-Xe^{131}, except that there will be an extra unit of charge contributed by the departure of the negative beta particle. About the second subgroup little can be said *a priori*; but it seems reasonable to expect that the mean state of ionization would be somewhat higher in these atoms than in those for which the vacancy cascades are not abetted by the nuclear transformation. We shall see in this paper to what extent experiment supplies information relevant to these expectations.

DISINTEGRATION SCHEME AND THE PURITY OF THE ACTIVITY

The main features of the decay scheme of Xe^{133}-Cs^{133} have been known since its early discovery among the fission products; they consist of beta emission having a maximum energy of 0.347 Mev, leading to a level at 82 kev in Cs^{133}, which, as mentioned above, decays in a rather even balance between gamma emission and

[1] A. H. Snell and F. Pleasonton, Phys. Rev. **107**, 740 (1957).
[2] A. H. Snell and F. Pleasonton, Phys. Rev. **100**, 1396 (1955).
[3] O. Kofoed-Hansen, Phys. Rev. **96**, 1045 (1954); and Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 15 (1955).
[4] F. Pleasonton and A. H. Snell, Proc. Roy. Soc. (London) **A241**, 141 (1957).

internal conversion.[5] This intense branch is the decay mode that concerns us particularly here, and it is indicated heavily in Fig. 1, but other, weaker features of the scheme are also known. A gamma ray of 380 kev, for example, was reported in 1951 by Ketelle, Brosi, and Zeldes,[6] and in the present work an examination of our gas samples by means of a scintillation spectrometer has revealed the same gamma ray, together with another having an energy of 160 kev, which decays with the 5.3 day half-life, and a third at 302 kev which was too weak to permit a measurement of the rate of decay. These observations fit well with the studies of Coulomb excitation in Cs^{133} that have been performed by Temmer and Heydenburg[7] and particularly by Fagg.[8] The Cs^{133} level scheme shown in Fig. 1 has in fact been taken from Fagg's paper. It should further be noted that Graham and Bell[9] have found the 82-kev level in Cs^{133} to decay with a mean life of about 10^{-8} sec.

Figure 1 also shows a metastable level in Xe^{133}, which was found by Ketelle, Brosi, and Zeldes[10] to have a half-life of 2.3 days. In fission product xenon this level is weakly populated in comparison with the ground state of Xe^{133}, but inasmuch as its gamma ray is fairly highly internally converted, it represented a possible contaminant that had to be watched. Other potential contaminants were Xe^{135} (9.4 hr) which is initially strong in fission-product xenon, and Xe^{131m} (12 day) which is initially weak but which would cause concern in old samples. (The magnetic spectrometer would give only an imperfect discrimination against these activities on the basis of their separation by two units from mass 133.) Our main reliance on purity from all three of the possible contaminating activities was based upon timing. The xenon was separated directly from uranium reactor slugs, usually about a week after the stop of irradiation; it was purified of krypton and supplied to us by the Operations Division of the Laboratory in samples that were sometimes much too strong for us to use in their entirety.[11] We allowed the xenon samples to decay for a further week or two, which reduced the 9.4-hour activity to utter negligibility, and permitted the 2.3-day activity to subside somewhat relative to the 5.3-day activity, and then we took measurements as desired until the samples were about a month old. After that the measurements were stopped because of the increasing relative strength of the 12-day activity. A calculation based upon published fission yield data, branching ratios, internal conversion coefficients, and half-lives of not only the xenon activities but also their iodine precursors showed that with an 8-day wait before xenon extraction, followed by another wait of 10 days, the decay rates of the 2.3-day and the 12-day activities (both of which would contribute solely to the internal conversion part of the charge spectrum) would be, respectively, 0.4% and 0.9% of the internal conversion rate in the 5.3 day Xe^{133}-Cs^{133}. The mass discrimination of the spectrometer would in addition reduce the registered ion counting rates for Xe^{131} by a factor of two or three, so it seems clear that advantageous timing is sufficient to give us the essentially pure 5.3-day activity.

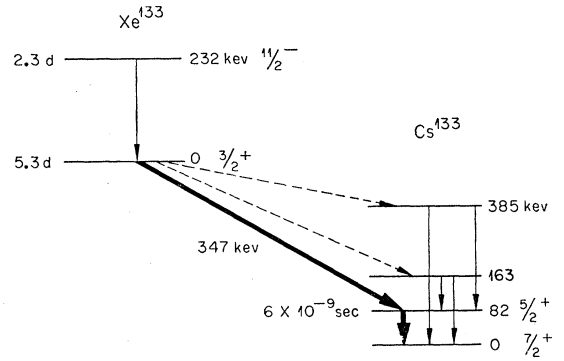

FIG. 1. The decay scheme of Xe^{133}-Cs^{133} according to present knowledge. The branch that is heavily indicated dominates greatly in intensity. The levels in Cs^{133} are taken from the Coulomb excitation work of Fagg (reference 8), and the spin and parity assignments are taken from Bergström (reference 5). The beta transitions shown by dashed lines are apparently too weak to have been observed independently; their existence is inferred from the detection of the 160-, 302-, and 385-kev gamma rays in the Xe^{133} activity.

CHARGE SPECTROMETER

The apparatus employed for these measurements was fundamentally as has been described previously,[4] and its mode of use has been essentially unchanged. However, some refinements have been introduced since our experiments on Kr^{85}-Rb^{85} and Xe^{131m}-Xe^{131}. The source and image apertures have been narrowed from circles half an inch in diameter to slots about a quarter of an inch wide and half an inch long, the exit aperture being "tailored" to fit the size and shape of the image as observed upon photographic film. (Protons from an ion source were used to obtain the photographs.) These changes have improved the resolution of the instrument slightly, but they are beneficial also in that, by reducing the pump-through rate of the radioactive gas, they have enabled us to obtain more counts from a given sample. The magnet has been modified so as to obtain field strengths of 5000 gauss or more, instead of the previous maximum of 2000 gauss; this permits us to use higher ion-collecting voltages, with a consequent substantial improvement in intensity. Finally, the detector (an electron multiplier) has been arranged to operate at a controllable bias voltage relative to ground,

[5] A discussion of these features of the decay scheme has been given by I. Bergström, Arkiv. Fysik. **5**, 191 (1952).
[6] Ketelle, Brosi, and Zeldes [private communication cited by Bergström (reference 5)].
[7] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **93**, 351 (1954).
[8] L. W. Fagg, Phys. Rev. **109**, 100 (1958).
[9] R. L. Graham and R. E. Bell, Can. J. Phys. **31**, 377 (1953).
[10] Ketelle, Brosi, and Zeldes, Phys. Rev. **80**, 485 (1950).

[11] We continue in our obligation to R. E. McHenry for the purification and preparation of the radioactive rare gas samples.

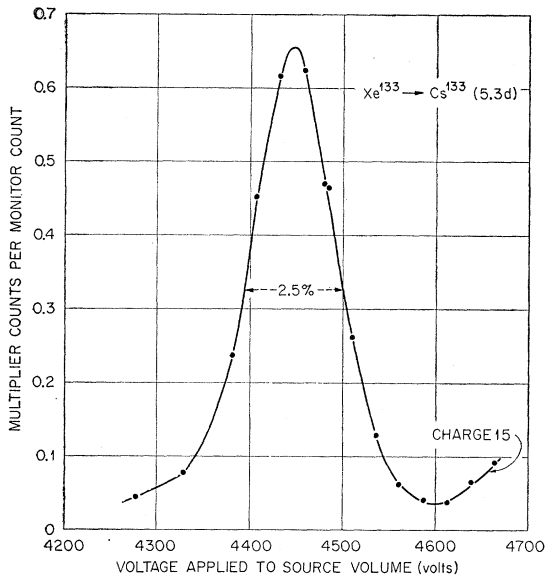

FIG. 2. An experimental trace over the charge 14 peak in Xe^{133}-Cs^{133} showing half-width in energy and resolution from the neighboring peak due to ions of charge 15.

thus enabling us to use the same artifice as is used in the collecting volume to ensure that the focusing forces are uniform for ions of different charge; *viz.*, to make the accelerating voltages always inversely proportional to the charge of the ion under investigation. It is not clear that this has made any difference at the output end of the spectrometer so long as the acceleration is applied across a gap bounded by plane parallel grids, but it seemed to be a worthwhile precaution that might guard against possible systematic errors. The whole source volume with its collecting electrodes has also been changed, the new one being free of neoprene gaskets and employing bakeable materials throughout its construction. The vacuum conditions have thereby been improved, but this has had little effect for gases like Xe^{133} for which a refrigerant can be used; its main purpose has been to make the apparatus capable of handling condensible vapors under acceptable conditions in future work.

The Xe^{133}-Cs^{133} measurements were made at varying times during the course of these changes, but the changes have not appreciably affected the shape of the charge spectrum as we have seen it. The performance of the spectrometer can be judged from Fig. 2, which illustrates a detailed sweep over the charge 14 peak of Xe^{133}-Cs^{133}, and gives an indication of the resolution from the neighboring peak at charge 15. Usually, however, we do not go over the peaks point by point, but simply make a single spectrometer setting at the apex.

EXPERIMENTAL RESULTS

The results of the Xe^{133}-Cs^{133} survey are given in Table I, and they are indicated as the heavily-shaded columns in the semilogarithmic histogram of Fig. 3. Our estimates of the fifty percent reliability limits of the intensities of the various charge states are also given in Table I. The figures for the errors are derived mostly from the statistics of counting, with some enlargement to allow for minor nonreproducibilities of the results as exhibited in various runs, taken at various times, from various gas samples, and during the course of the sundry modifications in the apparatus. A preponderant weight has been given to the final run, taken after the resolution of the spectrometer had been increased and after the introduction of the variable detector bias voltage. Possible nonuniformity of the efficiency of the multiplier in counting the ions of various charges was looked for by taking integral bias curves using the cesium ions themselves. No such variability was found with this particular multiplier in the state of activation that it had at that time, and therefore no corrections have been considered necessary as arising from this cause. The data were taken at total pressures of 2×10^{-6} and 1×10^{-6} mm Hg as indicated by ionization gauges attached to the source volume and the deflection chamber, respectively, and they show little or no sensitivity to source volume pressure through an increase by a factor of at least 4. Checks on the shapes of some of the lines have also been applied at times, and the relative intensities have been compared at different ranges of operating voltage.

It has been found necessary to apply a small correction to the measured intensities of the ions of high charge to compensate for the overlapping of adjacent peaks. An examination of peak shapes indicates that this is significant only for ions of charge 19 and above; at most it amounts to 6% of the measured intensity, and the data given in Table I have been corrected in this respect.

DISCUSSION

The division of the charge spectrum of Xe^{133}-Cs^{133} into two parts is immediately apparent in Fig. 3, and it seems natural at once to ascribe most of the part comprising a decrease through charges 1, 2, and 3 to atoms that escape internal conversion, and most of the

TABLE I. Distribution in charge of the ions produced in the radioactive decay Xe^{133}-Cs^{133}.

Charge of ion	Intensity (percent of decays)	Charge of ion	Intensity (percent of decays)
1	34.1 ±0.9	13	1.76 ±0.03
2	3.74±0.07	14	1.06 ±0.02
3	2.27±0.06	15	0.66 ±0.02
4	2.15±0.04	16	0.32 ±0.02
5	2.99±0.06	17	0.13 ±0.01
6	4.27±0.08	18	0.050 ±0.005
7	6.14±0.10	19	0.014 ±0.002
8	9.5 ±0.1	20	0.0075±0.001
9	12.3 ±0.1	21	0.0027±0.0007
10	9.0 ±0.1	22	0.0013±0.0006
11	6.06±0.07	23	0.0005±0.0005
12	3.32±0.04		

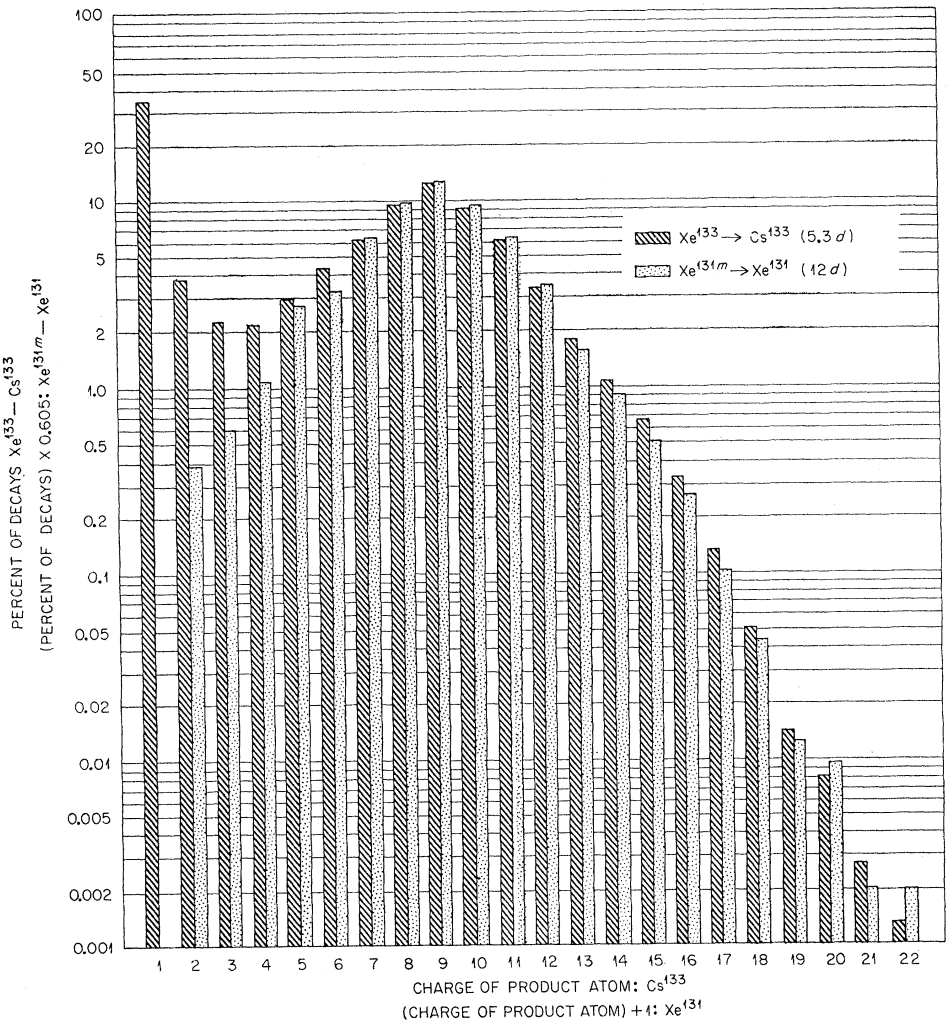

FIG. 3. The charge spectrum of Xe^{133}-Cs^{133} (5.3-day) is herein shown in bold columns, and that of Xe^{131m}-Xe^{131} is lightly indicated for comparison. The Xe^{131} spectrum has been shifted by plus one unit of charge in order to compensate for the difference in the nuclear charges of the product atoms, and its shifted intensity has been normalized so as to match the total number of internal conversions in Xe^{131m}-Xe^{131} to the total number of conversions in Xe^{133}-Cs^{133}.

remainder, comprising the rise to a maximum at charge 9 and a subsequent falling off to charge 23, to atoms that undergo internal conversion. The second part strongly resembles the charge spectrum produced by pure internal conversion in Xe^{131m}-Xe^{131}; the latter reaches a maximum at charge 8, which matches the charge 9 here observed when one remembers the extra unit of charge contributed by the departure of the beta particle. The intensity at charge 23 was measured for comparison with an anomalously high value that we had observed for charge 22 in Xe^{131m}-Xe^{131}. The present measurements do not repeat the anomaly, suggesting that we were probably correct in attributing it to impurities, since in the new and cleaner version of the apparatus, and with a slight shift in the setting because of the 131-133 mass difference, it has disappeared.

There is need, for the sake of further analysis, to attempt a resolution of the two parts of the spectrum in the region of overlap at charges 3 and 4. The only available information to which one can turn for guidance is again the Xe^{131m}-Xe^{131} data, and for present purposes this spectrum is reproduced as the lightly-shaded columns in Fig. 3, with a shift of +1 in charge and an adjustment in total intensity to match the total intensity of the internally-converted part of the Xe^{133}-Cs^{133} distribution. By taking differences between the column heights, one can then estimate that 3.4% of the decays produce charge 2 ions without internal conversion, 1.7% produce charge 3 and 1.1% produce charge 4, likewise without conversion. Beyond charge 4 the differences become small, one encounters an irregularity in the Xe^{131m}-Xe^{131} distribution, and one can only guess that in charges 5 and 6, together, perhaps a further 1.2% of the decays take place without internal conversion. In sum, the analysis would seem to indicate that 41.5% of the decays take place without internal conversion. The ratio 58.5/41.5, or 1.41 can be identified with the combined K, L, and M internal conversion coefficients on the grounds that a vacancy cascade initiated in any one of these shells is likely to lead to ions of charge 4 or higher, and that the number of conversions in the N and O shells is

likely to be negligible.[12] Independent measurements of the same quantity have been carried out by Bergström *et al.*[13] and by Graham and Bell,[9] using the methods of scintillation spectrometry whereby the intensity of the K x-rays of Cs is compared with the intensity of escaping 82-kev gamma rays. The resulting figures for α_{K+L+M} were 1.77 ± 0.09 and 2.06 ± 0.2, respectively, and they therefore lie somewhat higher than our 1.41, to which an error ±0.1 can perhaps be attached. Despite the fact that the agreement is close enough to support our interpretation in a general way, one wonders as to the source of the discrepancy. Possibly some little-understood surface effects are degrading ions of higher charge in our experiment, making charge 1 appear more intense than it should be; further work would be required to elucidate this as a source of systematic error. It seems to be difficult to fix the blame on an incomplete knowledge of the decay scheme, because to resolve the discrepancy in this direction, 12% of the decays would have to follow channels that avoid the 82-kev level and at the same time be free of internal conversion. In contradiction, our own observations with the scintillation spectrometer place an upper limit on the combined intensities of the unconverted 160-, 302- and 385-kev gamma rays at about 1% of the intensity of the unconverted 82-kev gamma ray, or about 0.3% of the disintegrations. Bergström[5] would set an even lower limit. A ground-state to ground-state beta transition of 12% intensity would seem to be unlikely if the spin and parity assignments shown in Fig. 1 are correct, for such a transition would be doubly forbidden, in competition with the allowed transition through the 82-kev level.

Returning now to the unconverted ions of charges 1, 2, 3, and 4, one observes that after resolution of the two parts of the spectrum their relative intensities give the initial part of the shake-off charge spectrum for xenon. One derives directly that as a result of beta decay in xenon (without internal conversion), the following probabilities can be established:

Probability of zero-electron loss	0.8;
Probability of one-electron loss	0.08;
Probability of two-electron loss	0.04;
Probability of three-electron loss	0.03;
Probability of more than three-electron loss	0.03.

More accurate figures will become available if the charge spectrum can in the future be measured for some xenon isotope that is more nearly a pure beta emitter, but it is interesting to note that these figures are sufficiently close to those of Kr^{85}-Rb^{85} [11] to suggest that these probabilities are at best only slowly-varying functions of Z, at least for atoms having the rare-gas electron configurations.

When we examine the high-charge slope of the charge spectrum, an unexpected feature emerges. This takes the form of a mild inflection, which actually is present also in Xe^{131m}-Xe^{131} but to such a slight extent that it could hardly be taken seriously, and which now emerges in Xe^{133}-Cs^{133} in accentuated form. In Xe^{131m}-Xe^{131}, charges 12 and 13 (plotted as 13 and 14 in Fig. 3) lie slightly below the smooth course of the intensities of neighboring charge states. In Xe^{133}-Cs^{133}, charges 12, 13, and 14 contribute to a deeper dip. The contrast between the spectra emerges clearly when one observes that through charges 9, 10, 11, and 12, Xe^{133}-Cs^{133} is the weaker of the two, while for charges 13, 14, 15, 16, 17, 18, and 19 the reverse is true. (Above charge 19 the errors become rather large, and the comparison becomes less certain.) There does actually appear to be a concentration of intensity in the high charge states of Xe^{133}-Cs^{133} which is not present in Xe^{131m}-Xe^{131}.

Two possible reasons come to mind for the difference in the shapes of the two distributions. They are:

(1) In Xe^{133}-Cs^{133} the $K/(L+M)$ internal conversion ratio is larger than it is in Xe^{131m}-Xe^{131}. It has been reported as 4.90 ± 0.15[5] and as 6.0 ± 0.2[9] for the former and as 1.70 ± 0.04 [5] and 3.4 [14] for the latter. If in $(Cs^{133})^+$ a greater proportion of the vacancy cascades start in the K shell than they do in Xe^{131}, the availability in the former of a larger number of multiplicative steps will lead on the average to a greater population in the high-charge states.

(2) There may be a "compounding" of the vacancy cascades with the shake-off process associated with the alteration of nuclear charge in Xe^{133}-Cs^{133} which is absent in Xe^{131m}-Xe^{131}.

The first of these possibilities is difficult to analyze further with present information, in the face of the complexity of the atomic situation. The second might appear to be capable of further analysis, for one might attempt to extract the shake-off effect from the combination, by making use of the shake-off probabilities derived from the low-charge end of the spectrum. Such an attack would lead to the establishment of a set of simultaneous equations in which the intensity of charge $i+1$ (the $+1$ is again for the beta particle) is expressed as the sum of terms consisting of the products of the shake-off probability for zero electrons with the probability of loss of i electrons in the vacancy cascade process, plus the product of loss by shake-off of 1 electron times the probability of loss of $i-1$ electrons in vacancy cascades, and so on. Such a procedure would be predicated upon the assumption that the shake-off and the vacancy cascades take place independently, which is plausible in view of the delay associated with the 82-kev level, although the concurrent assumption that the ionizing power of vacancy cascades will be

[12] A. E. S. Green and A. H. Snell, Proc. Roy. Soc. (London) **A242**, 400 (1957).

[13] Bergström, Thulin, Wapstra, and Aström, Arkiv. Fysik. **7**, 255 (1954).

[14] L. Cheng and J. D. Kurbatov, Phys. Rev. **78**, 319 (1950).

unaffected by a previous loss of electrons is perhaps less well founded. Our attempts at an analysis of this kind failed because the shake-off probabilities cannot be sufficiently precisely determined in the present work; if an independent shake-off spectrum can be accurately measured in the future, the analysis might be worth attempting anew.

The best explanation for the dip at charges 12, 13, and 14 in both Xe^{133}-Cs^{133} and Xe^{131m}-Xe^{131} would seem to be that it is an indication of structure such as one would expect to be associated with the individual electron shells in which the vacancy cascades are initiated, and that the main strength of the spectrum at the high-charge end derives from initial vacancies which have appeared in the K shell. This K-shell distribution then merges into a weaker mixture of different distributions, mostly at lower charge states, which derive from vacancy cascades which have started from other shells. This kind of structure would be illuminated by an experiment in which the charged ions are extracted from xenon gas under irradiation with x-rays, the energy of the x-rays being adjusted first at one side and then at the other side of an absorption edge. We understand that experiments of this kind are being contemplated in one or two other laboratories, and we shall await their outcome with interest.

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Disintegration of La^{135} and Confirmatory Experiments on Nd^{147}†

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The disintegrations of La^{135}, Ba^{135m}, and Nd^{147} have been studied with the help of magnetic spectrometers and scintillation counters. La^{135} decays almost entirely by electron capture. The half-life has been found to be 19.8±0.2 hr. Electron capture to the ground state takes place in 95–97% of all disintegrations. Gamma-rays of energies 104, 218, 265, 295, 367, 481, 588, 642, 862 kev have been found. There is a very weak positron spectrum. The internal-conversion coefficient of the line at 481 kev has been measured. The value $\alpha_K=0.0130$ indicates an $M1$ transition. The line at 862 kev has $\alpha_K=2.5\times10^{-3}$. The disintegration scheme is discussed. The internal-conversion coefficient of the line at 265 kev from Ba^{135m} has been found to be $\alpha_K=3.82\pm0.2$. The spectrum of Nd^{147} has been reinvestigated, confirming the scheme of Hans, Saraf, and Mandeville. The internal-conversion coefficient for the line at 92 kev has been found to be 1.52±0.05.

I. DISINTEGRATION OF LANTHANUM-135

1. Introduction

THE disintegration of La^{135} has been studied by various authors over the last fifteen years, but the information on the disintegration scheme has, so far, been quite incomplete. Weimer, Pool, and Kurbatov[1] irradiated barium with deuterons and found a substance in the lanthanum fraction having a half-life of 17.5 hr, decaying predominantly by electron capture and having a gamma ray, measured by absorption, whose energy was 880 kev. Chubbuck and Perlman[2] investigated the lanthanum fraction produced from the alpha-particle bombardment of cesium and found an activity decaying by electron capture with a half-life of 19.5 hr which they ascribed to La^{135}. Wapstra[3] prepared La^{135} by deuteron bombardment of barium and measured two gamma rays, using scintillation counter techniques, having energies of 485 and 660 kev, whose intensity ratio was 6:1. In addition, barium x-rays were found, which were about fifty times as strong as the gamma rays, indicating that approximately 98% of the disintegrations occurred by electron capture to the ground state of Ba^{135}. No indication of a gamma ray of energy 269 kev was found, indicating that the 29-hr metastable state[4,5] of Ba^{135} is not excited in the decay of La^{135}. Wapstra interpreted this to mean that the ground state of La^{135} probably has the configuration $d_{5/2}$ rather than $g_{7/2}$. Finally, Fagg[6] has found a state at 218 kev arising as a result of the Coulomb excitation of separated Ba^{135} by alpha particles.

The present work was undertaken to make a more detailed study of the radiations from La^{135} with the help of a magnetic spectrometer and scintillation counters. In addition, the radiations from the 29-hr Ba^{135} were reinvestigated.

2. Source Preparation

Electromagnetically separated Ba^{134} (50.8%), in the form of $BaCO_3$, was bombarded by deuterons in the Indiana University Cyclotron. Iron carrier was added as a gathering agent for lanthanum, and the trivalent hydroxides were precipitated with ammonia leaving the

† Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

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[2] J. B. Chubbuck and I. Perlman, Phys. Rev. **74**, 982 (1948).
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[5] W. H. Cuffey and R. Canada, Phys. Rev. **83**, 654 (1951).
[6] L. W. Fagg, Phys. Rev. **109**, 100 (1958).